Economic Comparison of White, “Green,” & Black Flat Roofs in the U.S. and Globally

ACEEE Buildings Summer Study
Asilomar/Pacific Grove, CA
August 13, 2012

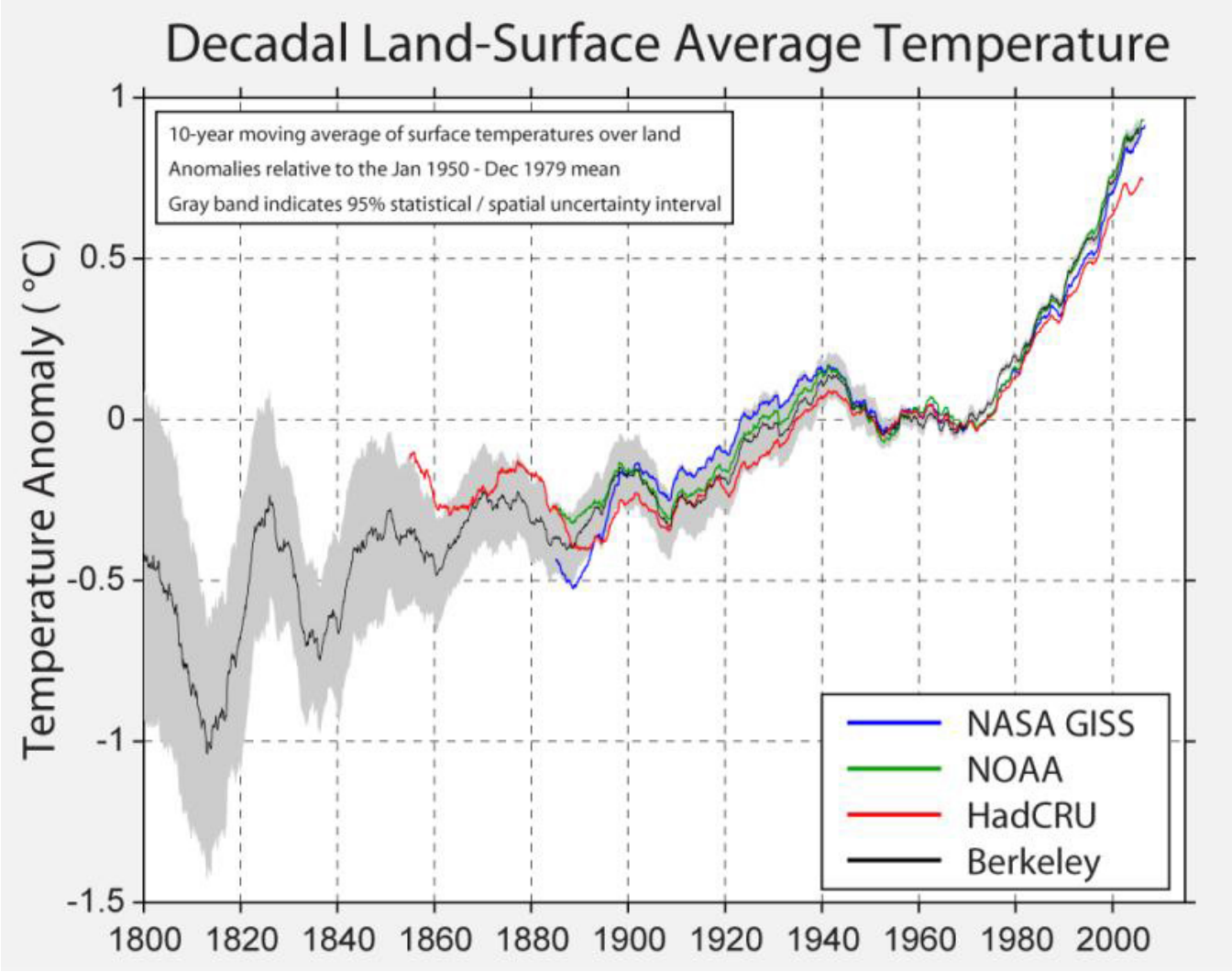
Arthur H. Rosenfeld, Former Commissioner
California Energy Commission

Distinguished Scientist Emeritus
Lawrence Berkeley National Lab.
AHRosenfeld@LBL.gov
916-295-3965

Presentation available at www.ArtRosenfeld.org

Filename: ACEEE v1 ROSENFELD Asilomar 2012.pptx

Berkeley Earth Surface Temperature Project



Richard Muller
Robert Rohde
Judith Curry
Donald Groom
Bob Jacobsen
Saul Perlmutter
Arthur Rosenfeld
Charlotte Wickham
Jonathan Wurtele

executive director:
Elizabeth Muller

special advisor:
David Brillinger

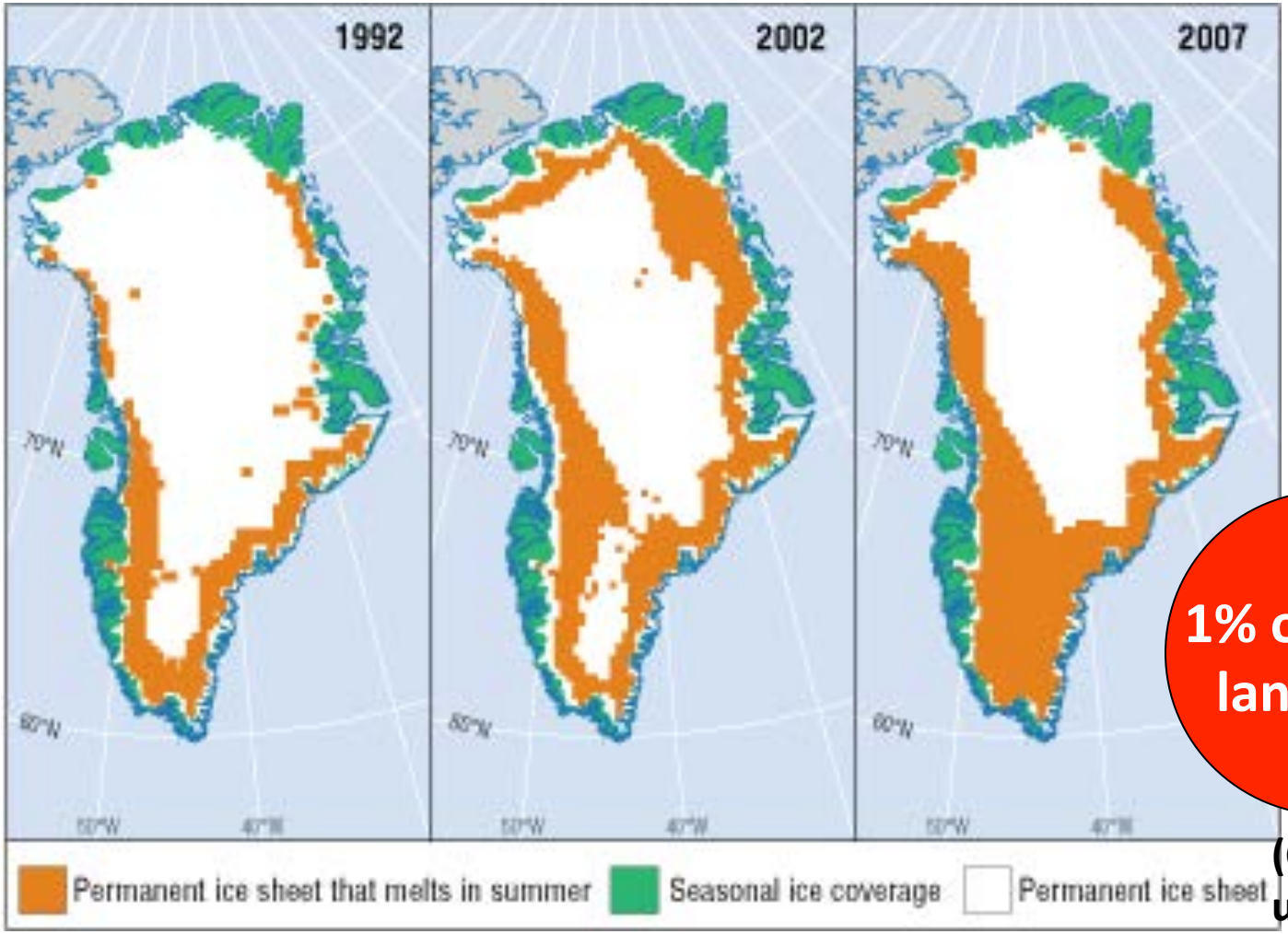
Novim, U. Calif. Berkeley, Lawrence Berkeley Lab, Georgia Tech, Oregon State

preprints and merged data now online at www.BerkeleyEarth.org

BERKELEY EARTH SURFACE TEMPERATURE

Greenland is about ¼ the size of continental US

Permanent ice sheet has melted substantially



1% of world land area

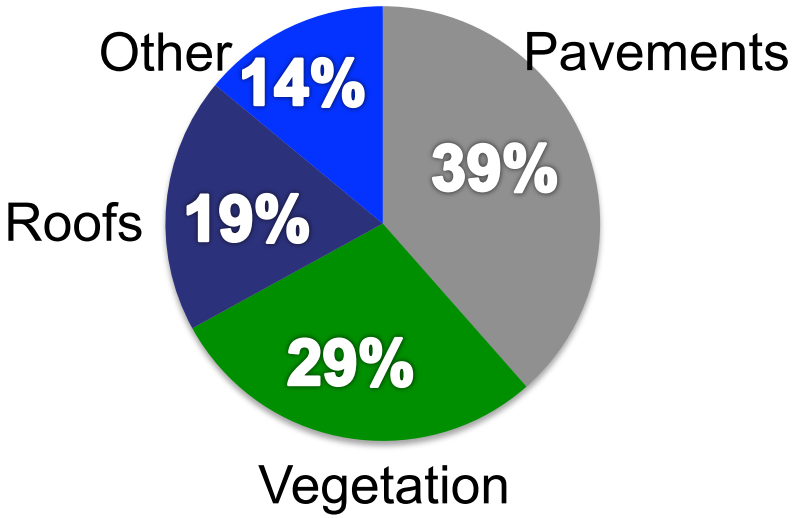
(Comparable to global urban space)

http://hungerreport.org/2010/report/chapters/four/making-the-connections

The urban heat island effect

- Human activity, combined with dark roofs and pavements, make cities hotter than surrounding rural areas.
- Higher temperatures lead to greater energy use, lower air quality, and a reduced quality of life in urban areas.

Urban fabric above tree canopy

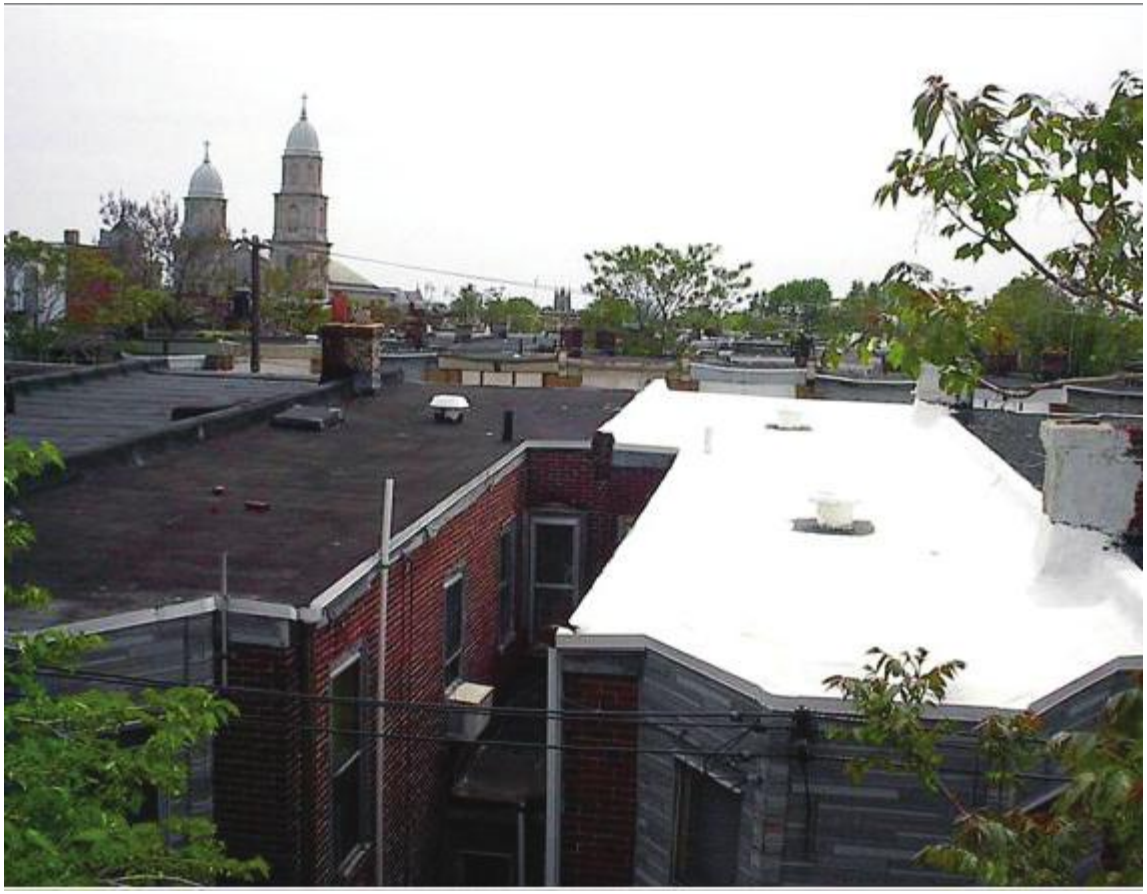


My Involvement

- 1980 – Heat island mitigation: reduces A/C load, cools cities, reduces ozone
- 1995 – Chicago heat wave: 1000 excess deaths
- 2003 – European heat wave: 52,000 excess deaths ➔ EPIPHANY
- 2005 – CA Title 24, effective 2007: “Flat roofs shall be white”
  - Green roofs were uninteresting afterthought
- 2009 – Akbari et al.: 5% reduction of global warming
- 2010 – LBNL Director Steven Chu promotes white roofs
- 2011 – Secretary of Energy Steven Chu promulgates white roof order
  - Include green?? ➔ Timely topic for Julian Sproul’s undergraduate thesis
- 2012 – Sproul, Wan, Rosenfeld draft on web (www.ArtRosenfeld.org)

1995: Chicago Heat Wave, 739 reported* deaths

The highest risk group lived on the top floors of buildings with black roofs

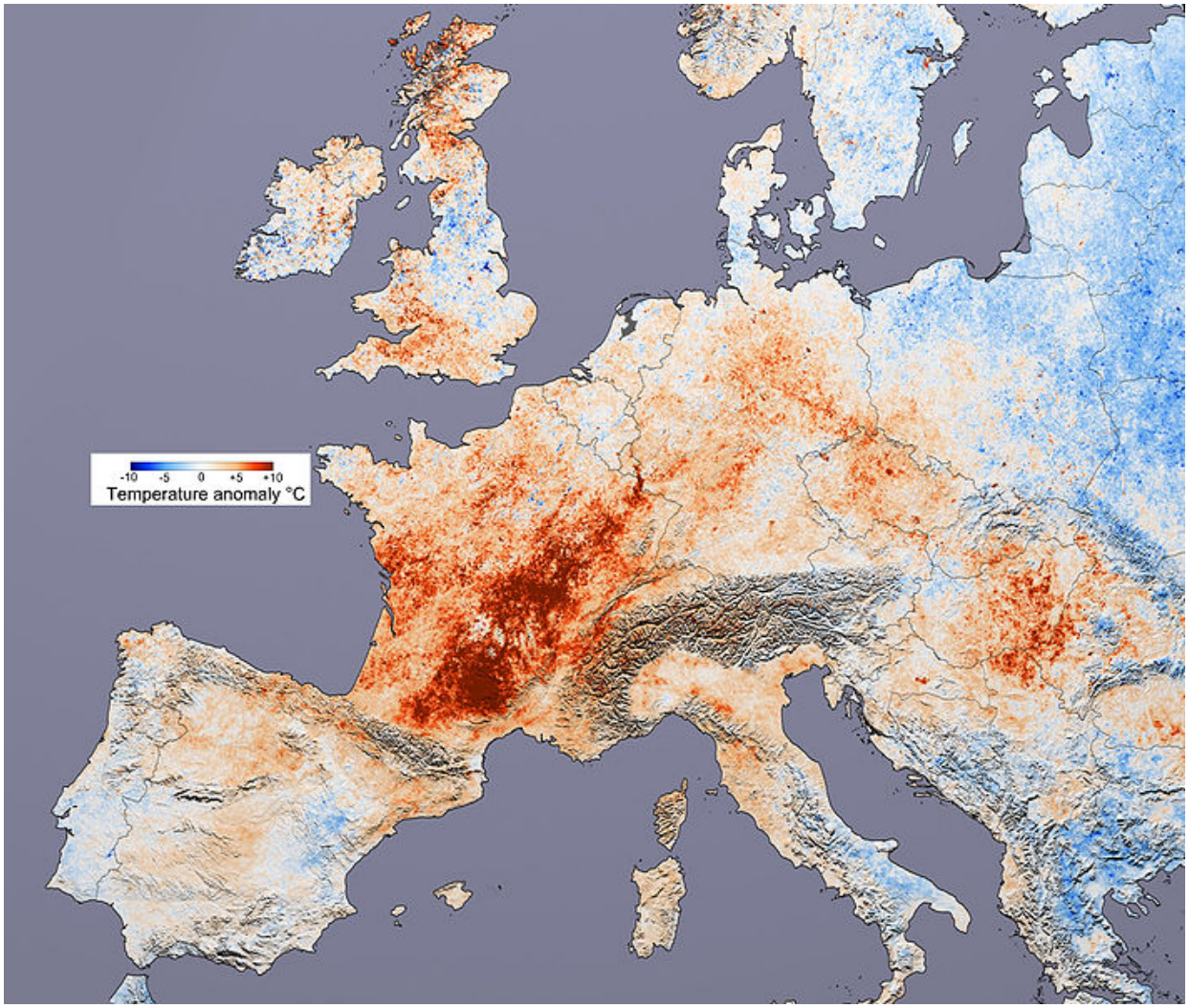


*** More than 250 additional deaths not autopsied**

Aug. 2003: European heat wave

Temperature anomalies reached 10°C

52,000 Europeans died—18,000 Italians (2006 assessment)



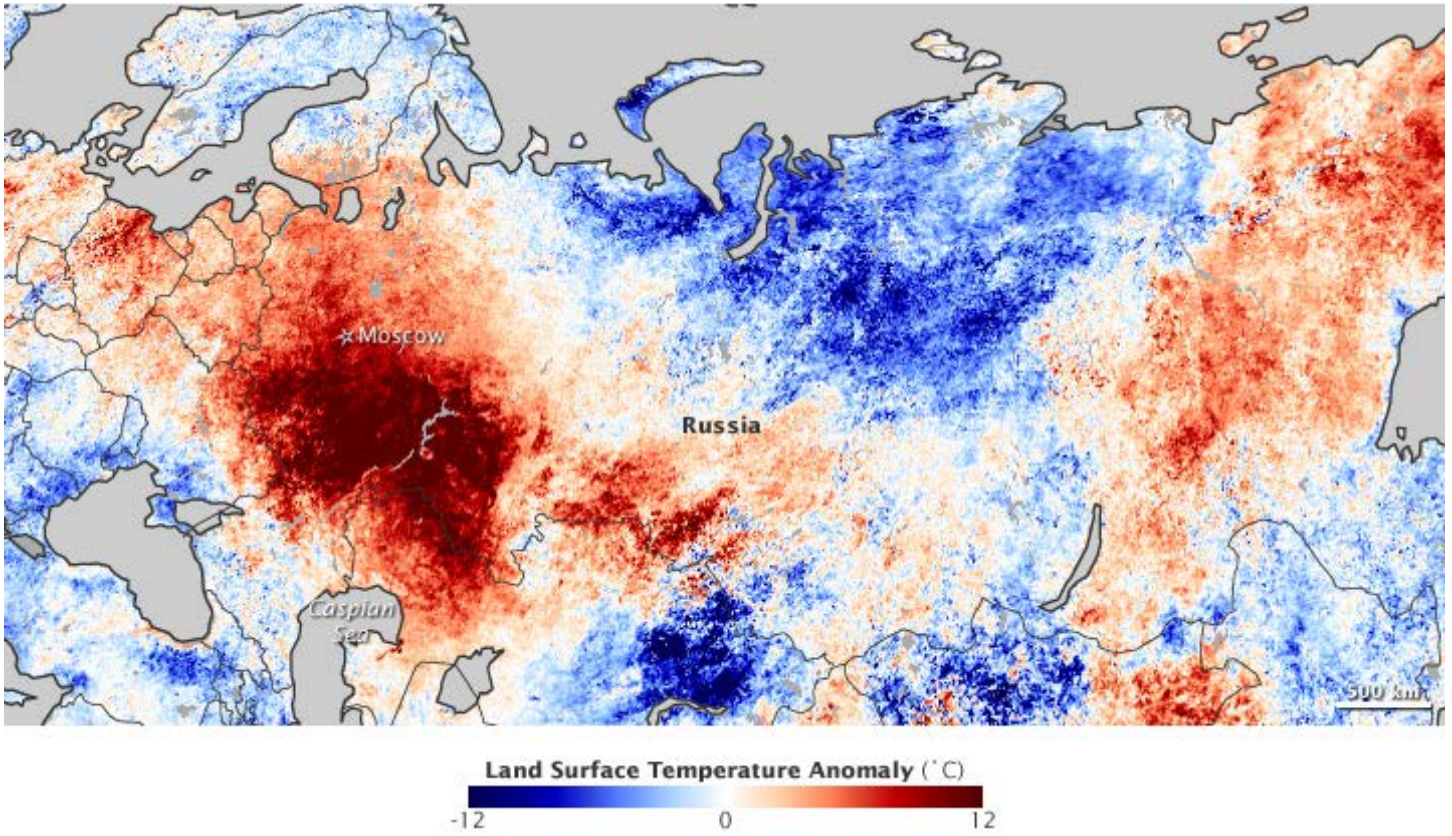
Country	Fatalities
Italy	18,257
France	14,802
Germany	7,000
Spain	4,130
England & Wales	2,139
Portugal	2,099
Smaller countries	4,025
Total of above	**52,452**

http://earthobservatory.nasa.gov/IOTD/view.php?id=3714

2010: Heat wave centered Southeast of Moscow

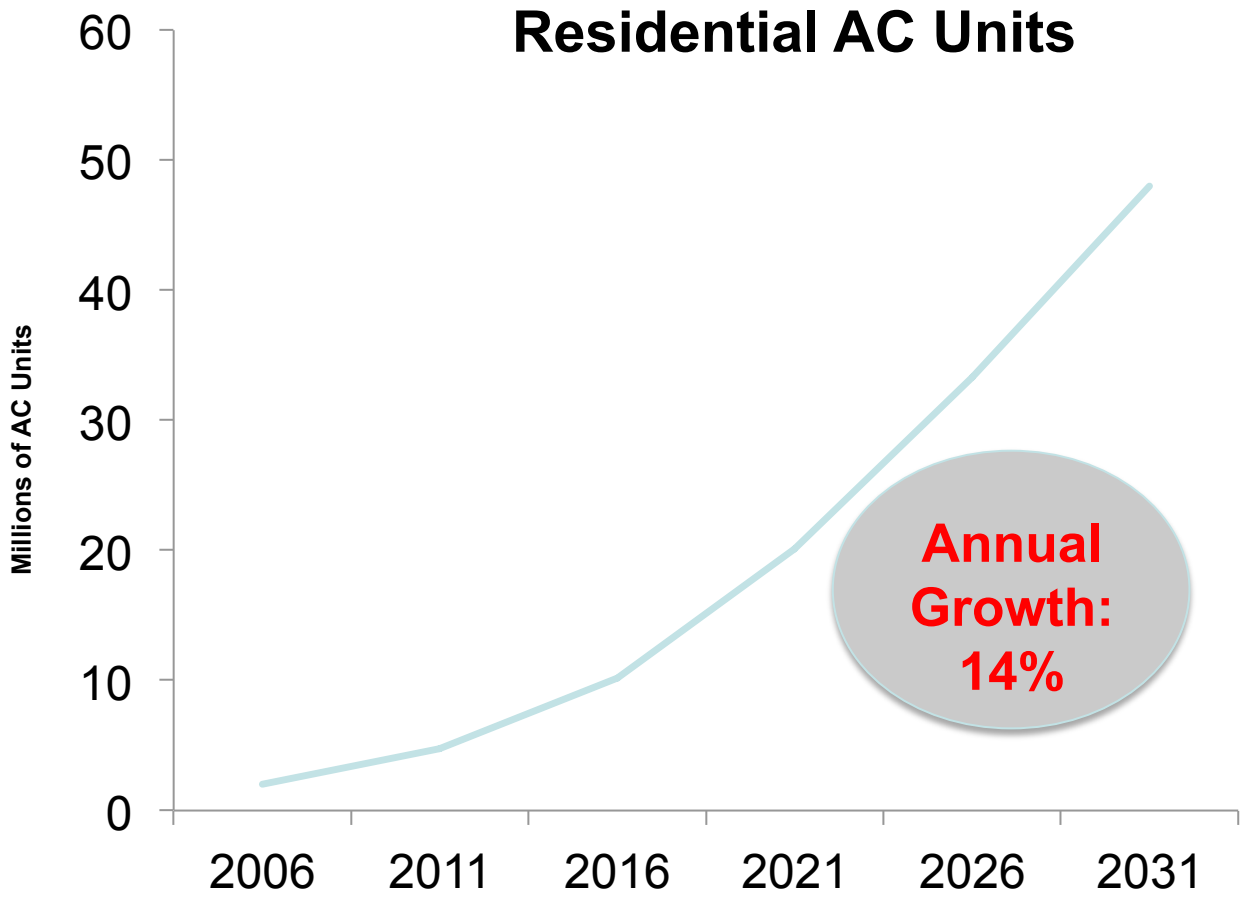
Temperature anomalies reached 12°C

10,000-15,000 deaths



http://takvera.blogspot.com/2011/10/climate-change-fractional-attribution.html

New AC Load: India



Source: World Bank

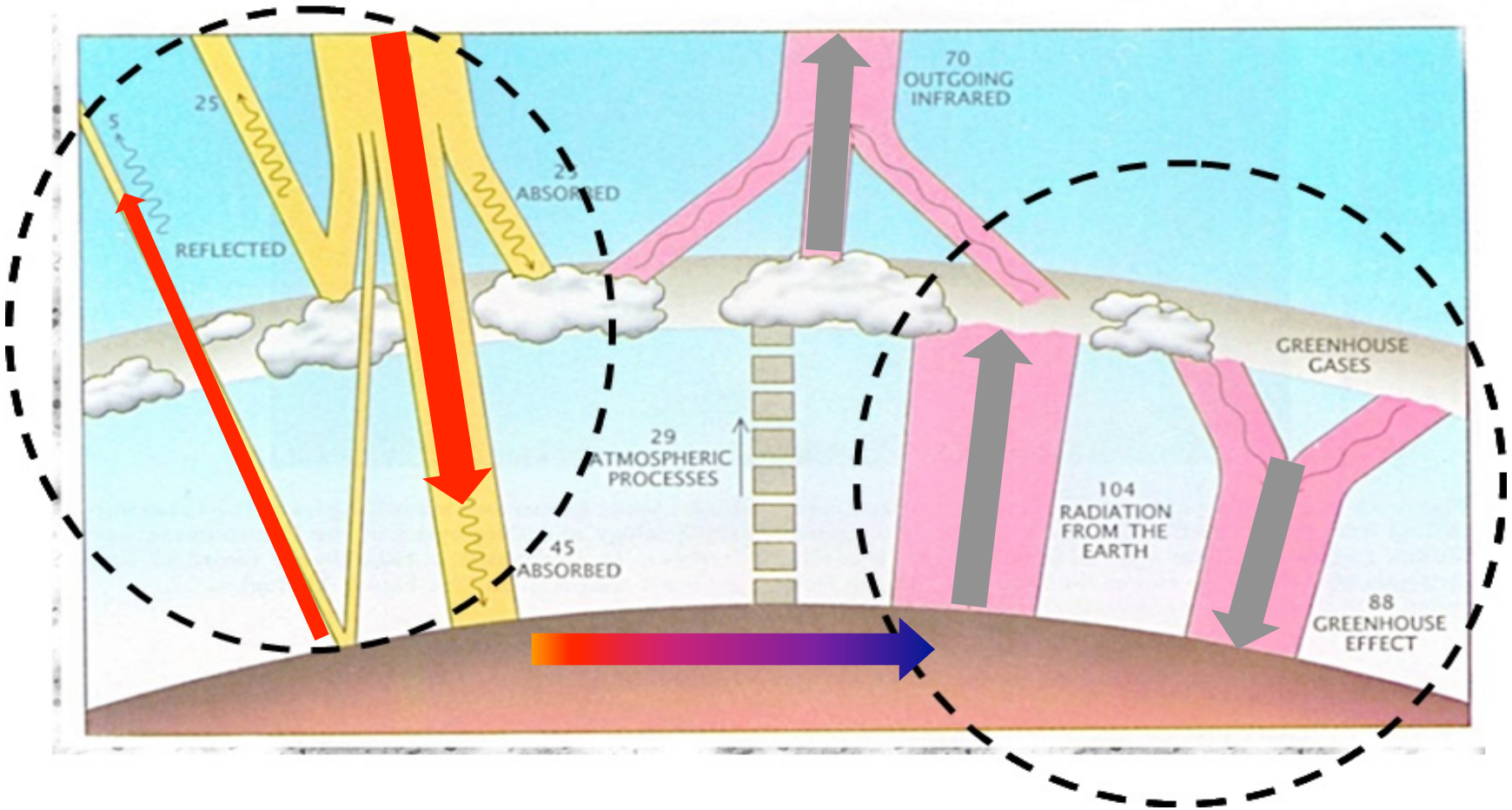
A Real-World Example of Cooling

The whitewashed greenhouses of Almeria, Spain have cooled the region by 0.8 degrees Celsius each decade compared to surrounding regions, according to 20 years of weather station data.

Source: Google Earth

Cooling our planet

Solar-reflective surfaces cool the globe via “negative radiative forcing”



Source: Intergovernmental Panel on Climate Change (IPCC)

GLOBAL COOLING: whitening 100 m^2 (~1000 ft^2) of gray roofing cancels out the **emission** of 10 t of CO_2

14

How much CO_2 equivalent is offset if we whiten all eligible urban flat roofs world-wide? (i/ii)

- Answer: **24 Gigatonnes (Gt)**
  - 2/3 of a year's worldwide emission
  - Gigatonne = billion metric tons

- If implemented over 20 years (the life of a roof or a program) this is ≈ 1.2 Gt/year.

How much CO_2 equivalent is offset if we whiten all eligible urban flat roofs world-wide? (ii/ii)

- Offset is equivalent to **taking half the cars in the world off the road for 20 years**.
  - There are about 600 million passenger cars world wide, and they each emit ≈ 4 t CO_2/ year.

In terms of avoided power plants

- Full white roof potential avoids 500 medium-sized coal fired power plants or 1,000 medium-sized gas fired power plants
- For comparison, global power plants emit annually ~15 Gt CO2, equivalent to the output of 6,000 typical midsized power plants (2/3 coal, 1/3 gas)
- Further comparison – the real avoided emissions from global CFL deployment is equivalent to 400 power plants.

White roofs around the world

…in Santorini, Greece

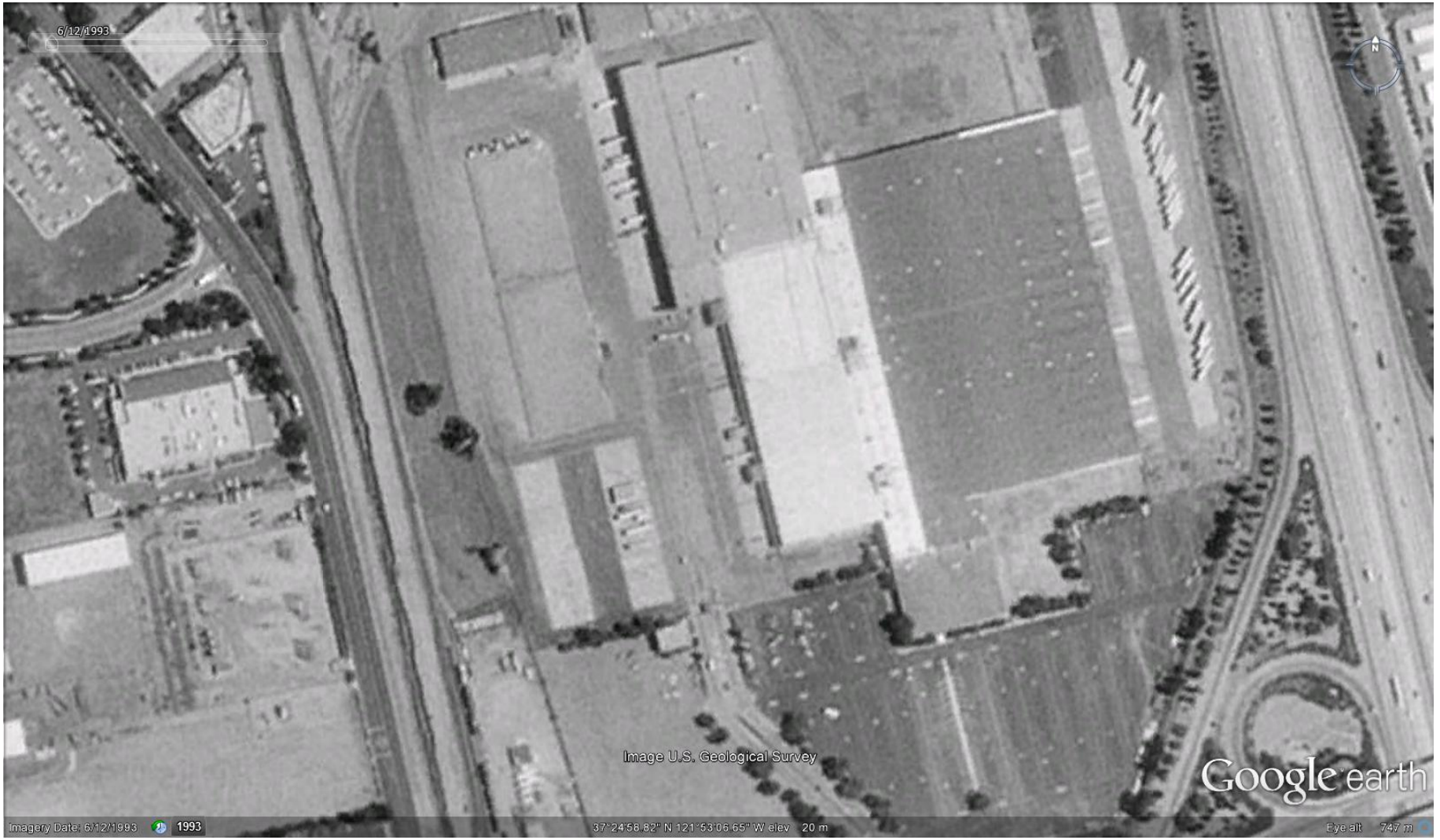
…in Hyderabad, India

…and widely in the state of Gujarat, India.

Walmart store in northern California, ~2006

UC Davis switched to white membranes ~1980—Congrats, and some still in service 30 yrs later

San Jose, CA – 1993



San Jose, CA – 2011

Global Cooling: Green vs. White

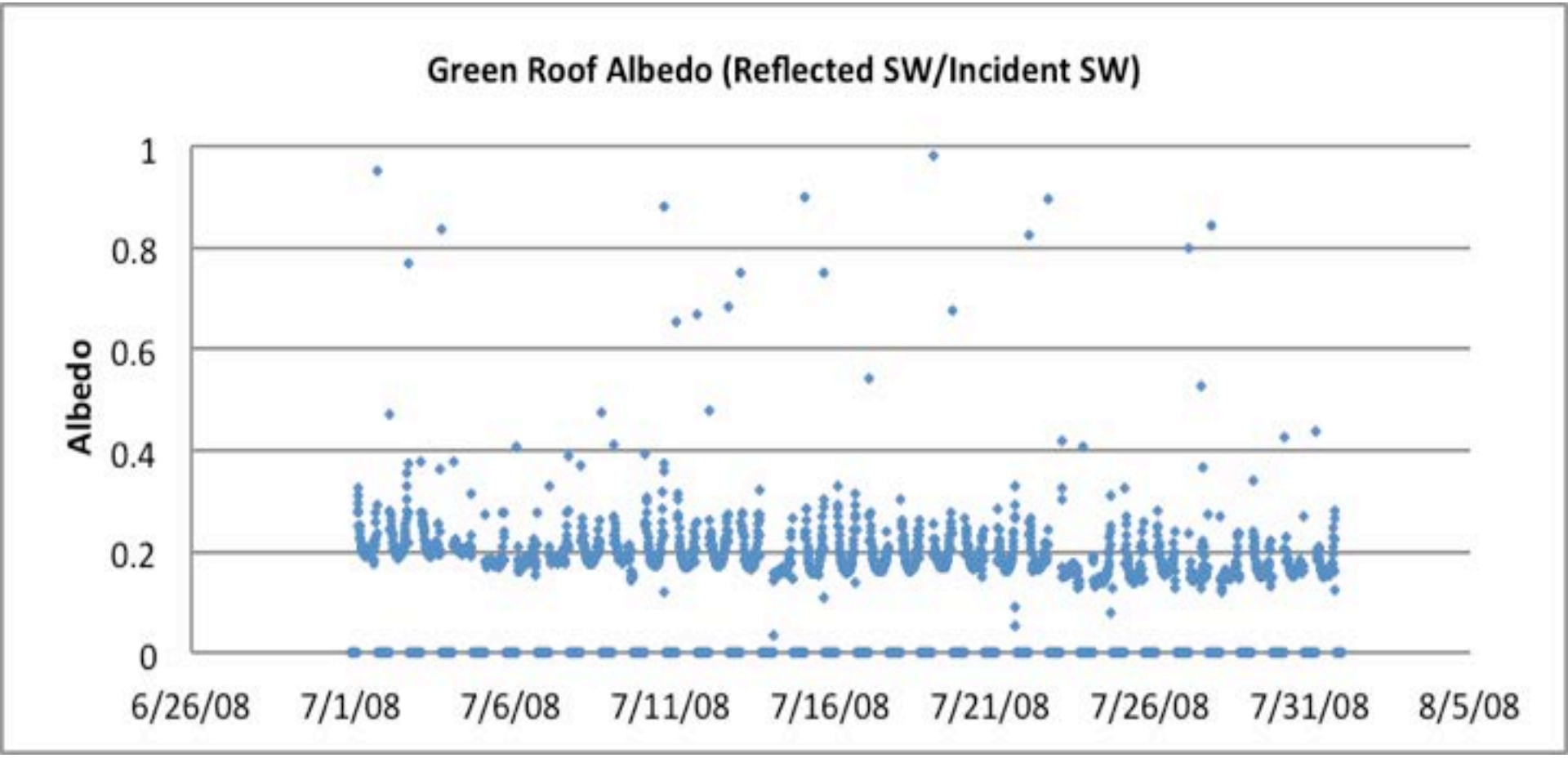
Aged reflectance of white roofs average 0.55, extensive green roofs average 0.20

→White roofs reflect nearly three times as much incoming sunlight back into the atmosphere

→ Based on Akbari et al. 2009 statement: "Making 100 m^2 (1000 ft^2) of gray roofing white offsets the **emission** of 10 t of CO_2 over the 20 year service life of the roof"

→White roofs have a one time offset of ~10 t of CO_2 whereas green roofs only have a one time offset of ~3 t of CO_2

Green Roof Solar Reflectance (Albedo)

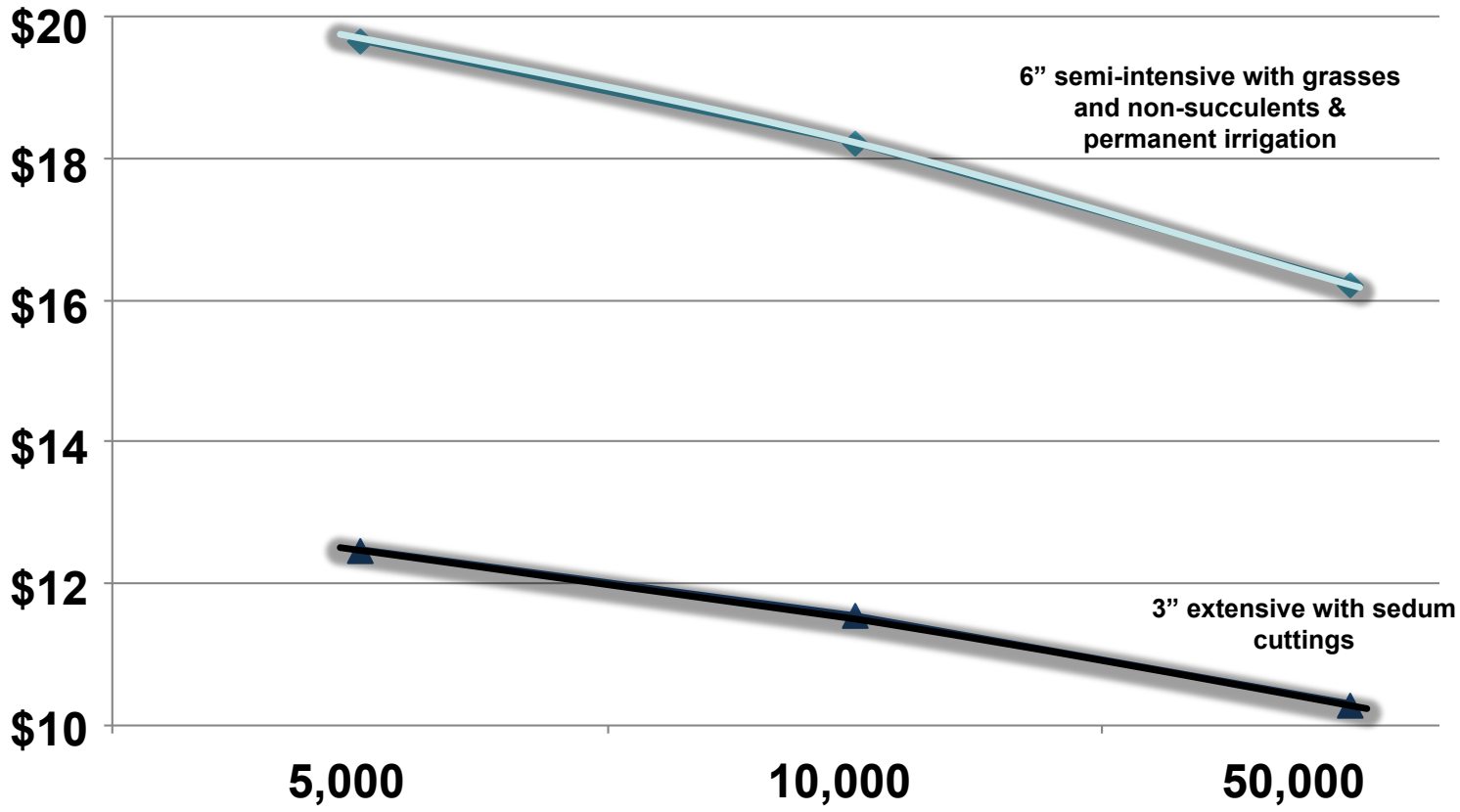


Solar Reflectance of an extensive green roof measured in New York in July 2008

Source: Gaffin et al. 2010

Cost benefit analysis: Conventional versus Green roof

- Installation costs ($ per square foot):



- Maintenance costs: $0.20 to $0.30 per square foot per year

Choosing Your Roof: A Decision Tree

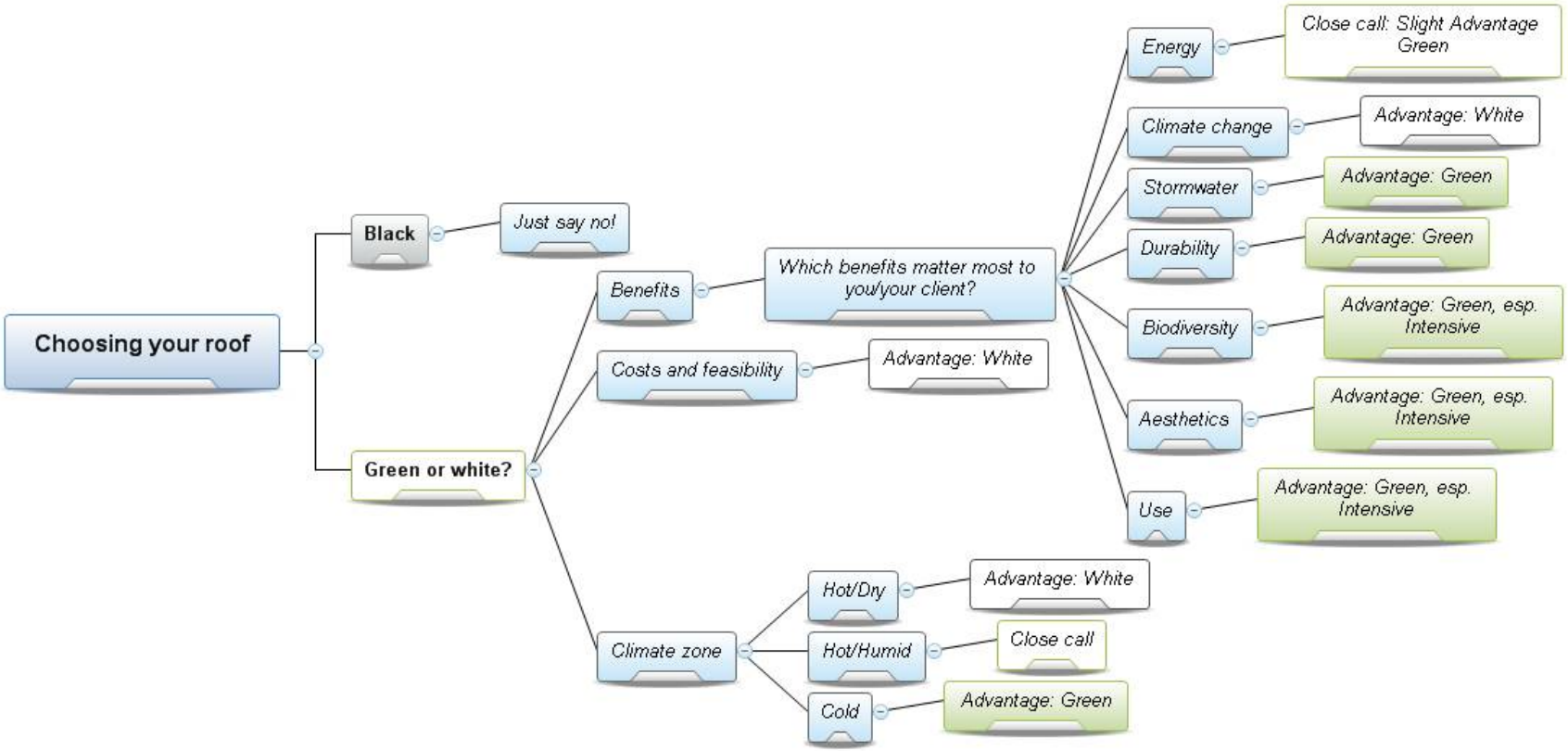
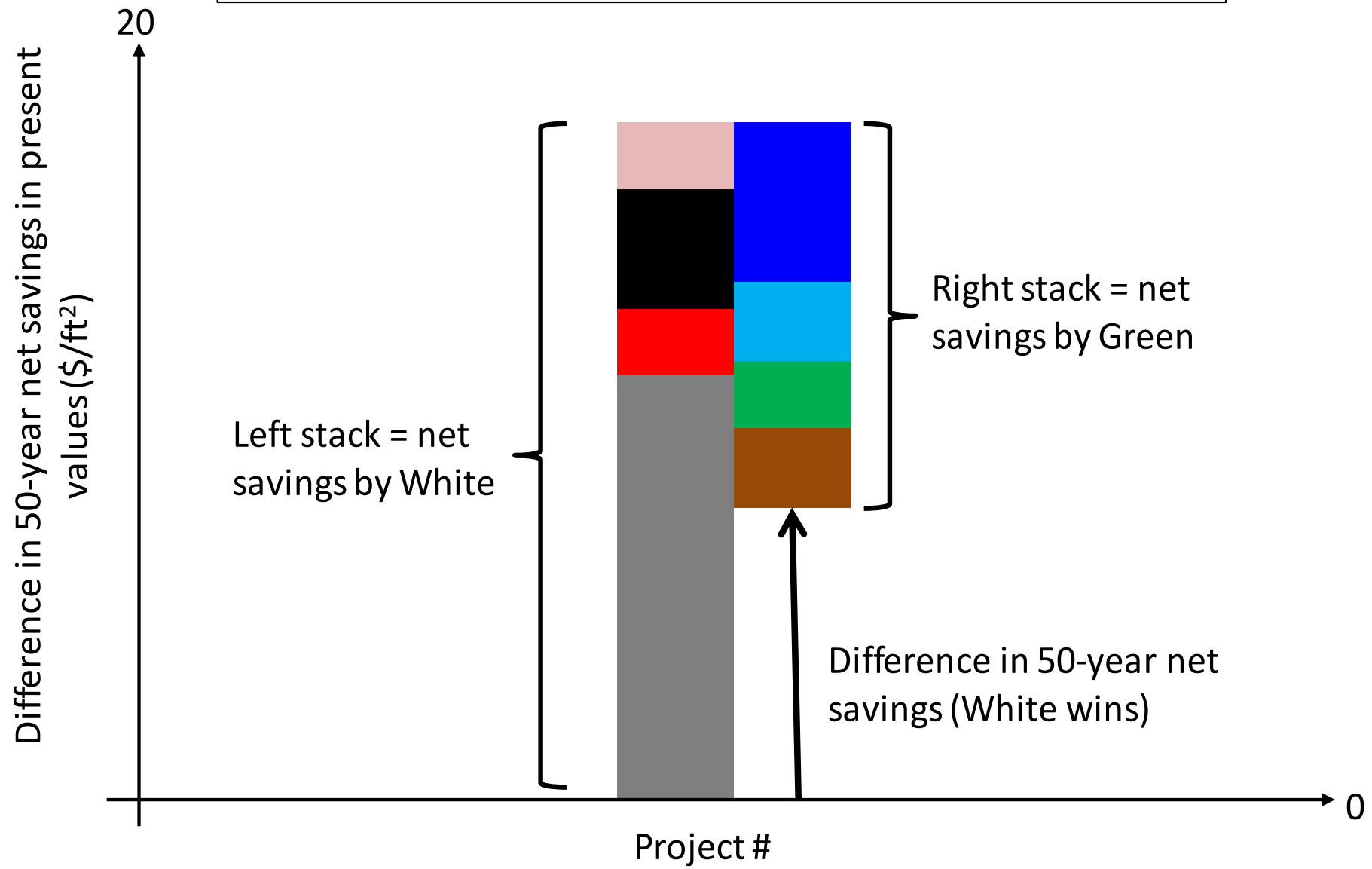
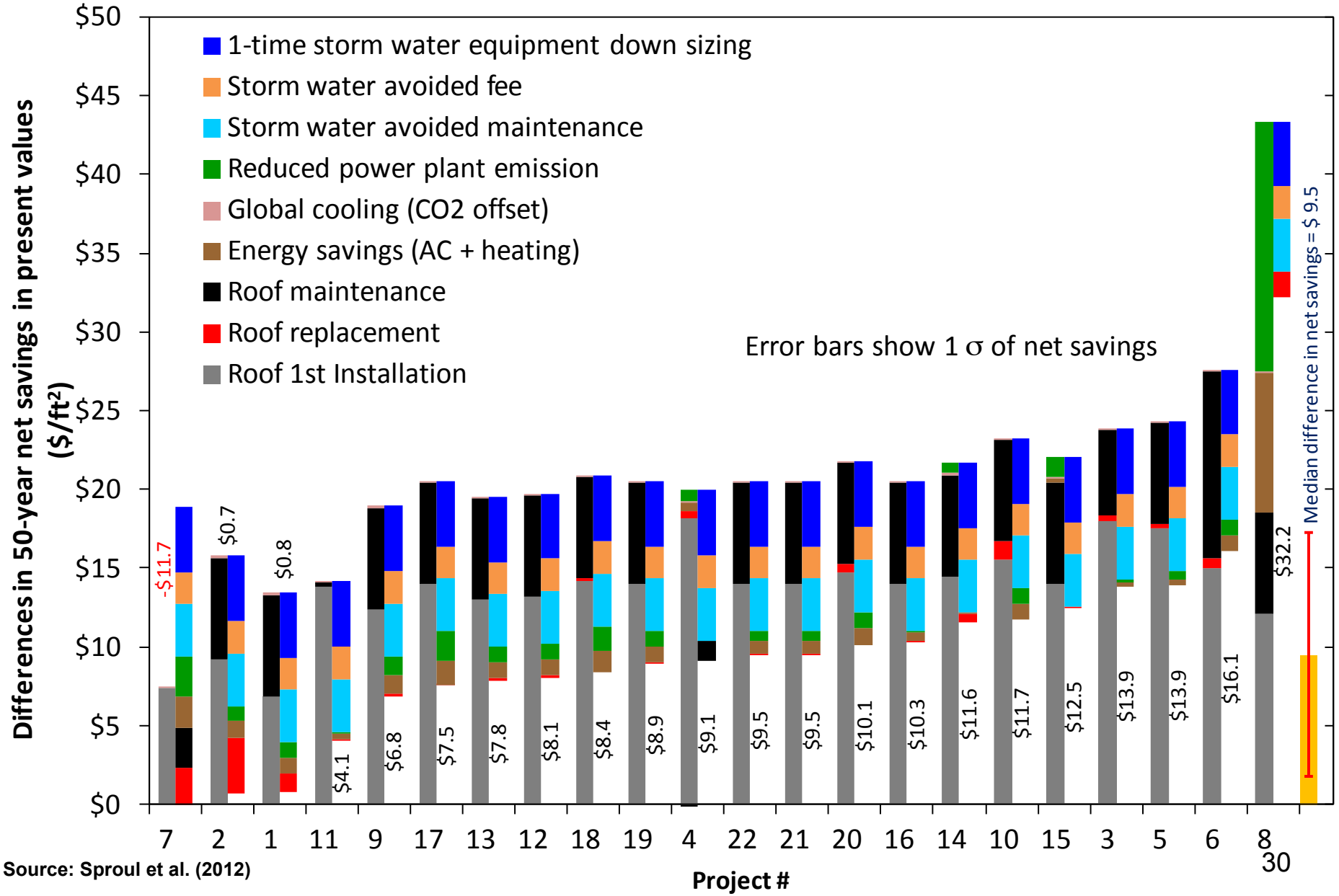


Figure 2a). How to read White – Green stacks in Figure 2b)

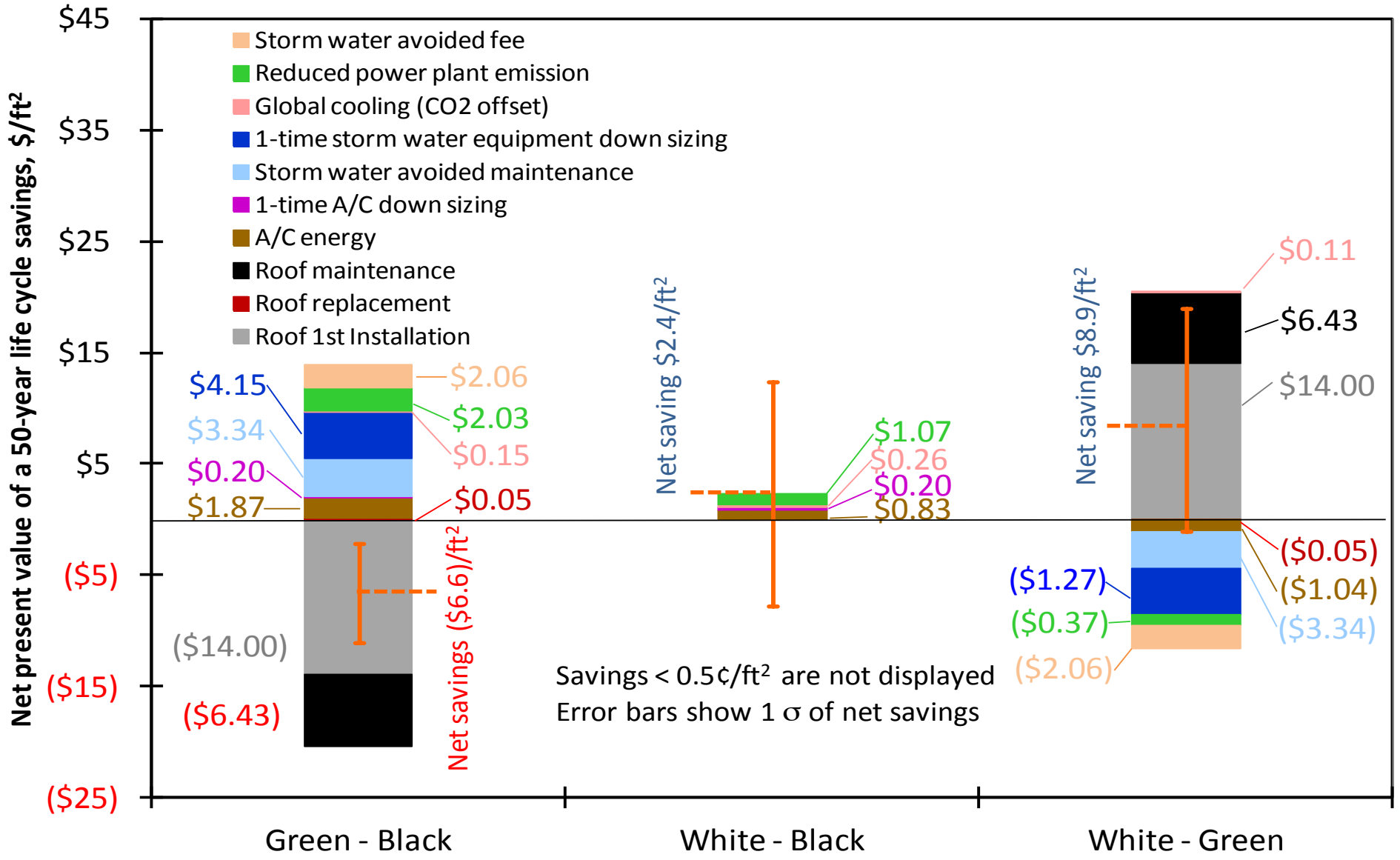


Source: Sproul et al. (2012)

50-Year Life-Cycle Cost SAVINGS for White – Green



Source: Sproul et al. (2012)

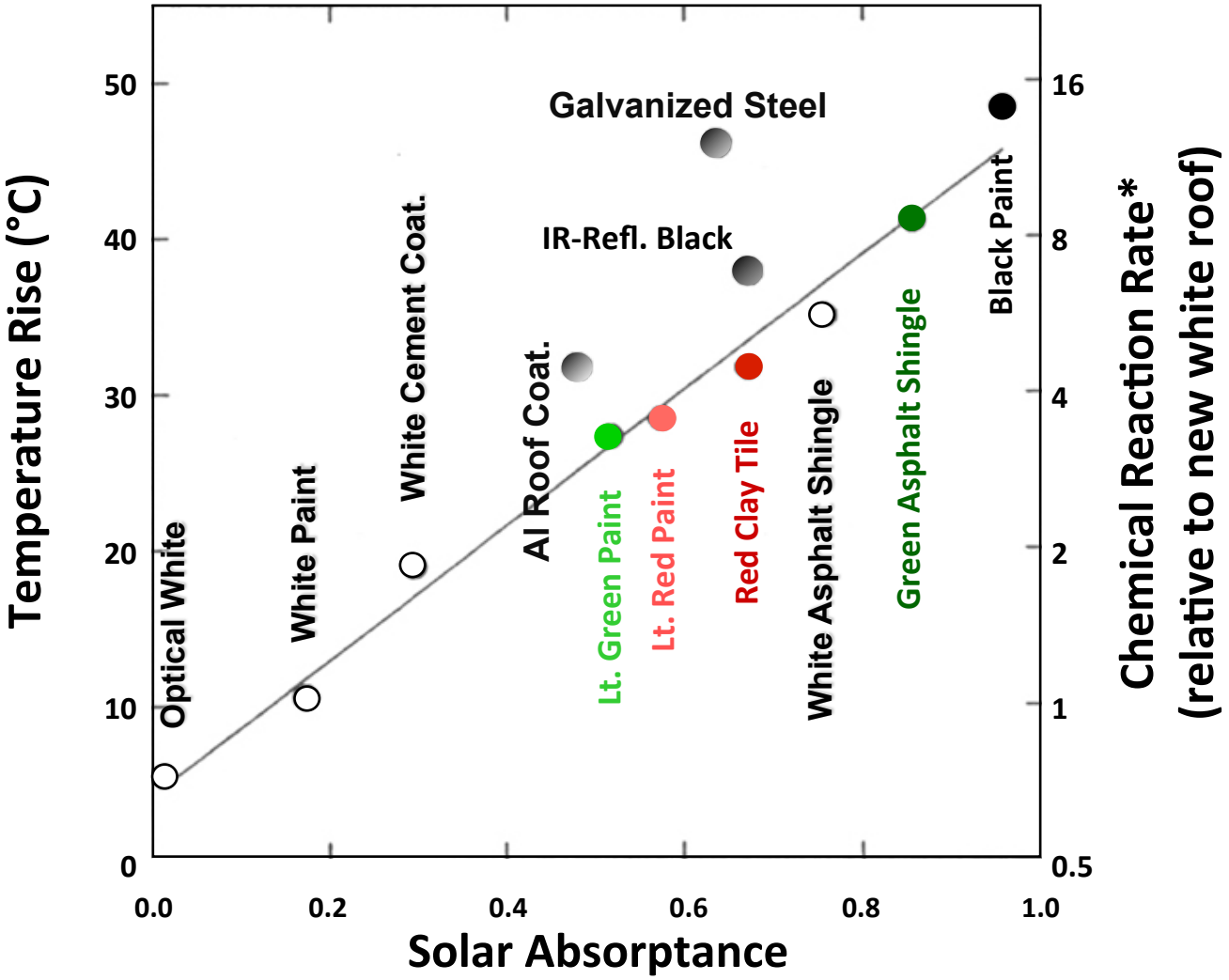


Source: Sproul et al. (2012)

Resources on the web

- **LBNL – Heat Island Group**
  - HeatIsland.LBL.gov
- **Art Rosenfeld's website**
  - www.ArtRosenfeld.org
  - For Sproul et al. and other papers
  - For these slides, select "Presentations" tab
- **Global Cool Cities Alliance**
  - www.GlobalCoolCities.org
- **Cool Roofs and Cool Pavements Toolkit**
  - www.CoolRoofToolkit.org

Reflective roofs stay cooler in sunlight and should age more slowly



*Berdahl P, Akbari H, Levinson R, Miller W. (2008) "Weathering of roofing materials – An overview" *Construction and Building Materials.* 22:423-433. doi:10.1016/j.conbuildmat.2006.10.015

White roofs, cool-colored roofs save money and can even avoid the need to air condition

OLD

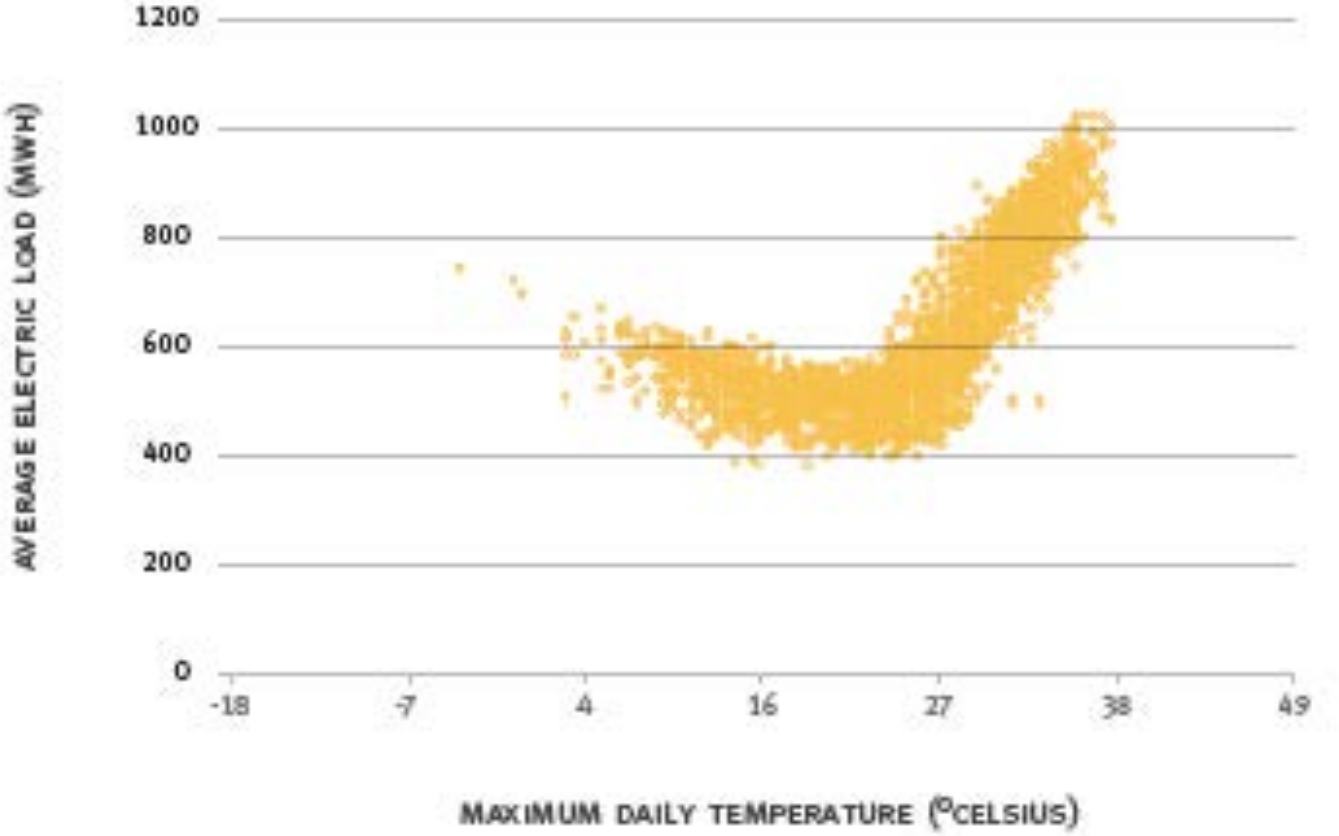
flat, white

pitched, white

NEW

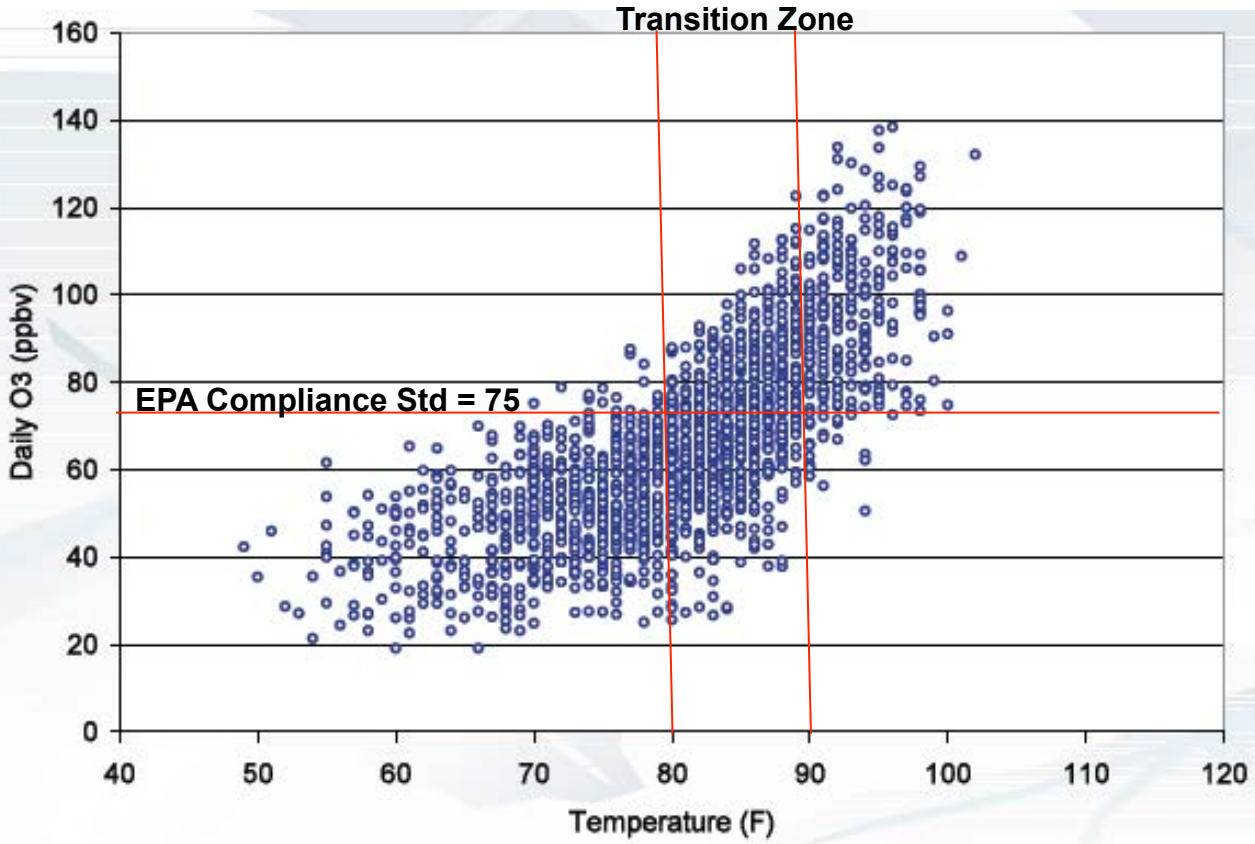
pitched, cool & colored

Electricity Load and Temperature



Adapted from Sailor, D. J. 2002. Urban Heat Islands, Opportunities and Challenges for Mitigation and Adaptation. Sample Electric Load Data for New Orleans, LA (NOPSI, 1995). North American Urban Heat Island Summit. Toronto, Canada. 1–4 May 2002. Data courtesy Entergy Corporation.

Smog Formation and Temperature



Maximum surface temperature at BWI versus peak 8-hr ozone concentrations in the Baltimore non-attainment area for the period May-September, 1994-2004 (Piety, 2007).

Source: Maryland Commission on Climate Change